IDENTIFICATION OF TASKS SENSITIVE TO HYPERBARIA WITH DETERMINATION OF TIME INTERVAL EFFECTS ON PERFORMANCE

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SUMMARY PAGE

THE PROBLEM

To identify tasks sensitive to the stresses of hyperbaric environments and to determine the effects of variation in the time interval between such exposures upon task performance.

FINDINGS

An adaptive tracking task proved sensitive to narcotic effects of 7 ATA air, two mental arithmetic tasks did not. With intervals of 5-20 days between exposures at 7 ATA, much larger decrements in tracking performance were found in the first exposure than in the second. Preceding, or intervening, exposures at 2 ATA did not moderate narcotic effects of the "deeper" exposure in any way.

APPLICATION

The findings suggest that: (1) susceptibility to narcosis during an hyperbaric exposure can be reduced substantially by an orientation exposure only if its profile closely resembles those working exposures to follow; and (2) studies of the depth-performance relationship must provide for measurement of the effect of sequence of exposures when subjects are tested at several depths.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Unit M4306.03-1020DXC5. The present report is Number 4 on this work unit. It was submitted for review on 7 Sept 1973, approved for publication on 14 Sept 1973 and designated as NavSubMedRschLab Report No. 762.

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ABSTRACT

Eight Navy hyperbaric chamber technicians performed adaptive tracking and mental arithmetic tasks during four weekly 30-minute exposures; two each at pressure equivalents of 33 and 198 foot depths. Order of exposures was counterbalanced over subjects.

Much larger decrements in tracking performance were found in the first 198-foot exposure than in the second. The findings suggest that, until now, the effects of situation-specific experience on "nitrogen narcosis", as opposed to those of general experience in hyperbaric contexts, have been seriously under-estimated in practice and in studies of the depth-performance relationship.

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INTRODUCTION

The effects of the environment on performance, particularly as it relates to the respiratory medium, (Priestley, 1775)[1] is one of the most venerable topics for human factors research. A major recent impetus to research in this area has come from the pollutant explosion and its discovery by the general public and the Congress (Cohen and Margolis, 1973).[2] The major ancient barrier to progress in understanding the effects of environmental events of all types on performance is the underdeveloped state of performance measurement. Underdevelopment in this case is not the result of inactivity or failure of a consensus regarding the existence of a problem. The level of activity may be inferred from the report by Finley et al. (1970)[3] in which they summarized the literature on 500 tests developed to measure 75 dimensions of behavior. The consensus was stated by Chiles (1967)[4] in his introduction to proceedings of a symposium on performance measurement, "... there is in fact no methodology that is generally accepted by researchers on such problems, ..." Similar views have been expressed with regard to the more circumscribed area of research on nitrogen narcosis (Jennings, 1968; Fowler, 1972).[5,6]

This dissatisfaction with the state of the art is objectively based; experiments seemingly identical in all major aspects have produced contradictory results (Bennett, 1969).[7] In response to that situation a program of research directed at identification of those task parameters which affect the reliability, sensitivity, and validity of performance measures was initiated at NAVSUBMEDRSCHLAB. This report describes an attempt to validate in a hyperbaric test some products of that program. As the experimental design evolved it was possible, also, to assess the effects of a variable believed to be important to both the methodology of performance measurement and the safe and efficient conduct of diving operations.

Performance measures with a moderately successful record for detection of environmental influences on behavior, mental arithmetic and two-dimensional tracking, had been chosen for parametric study. As these measures were implemented, it was also possible to manipulate some of the characteristics which are widely believed (Finan et al., 1949; Poulton, 1965; Wilkinson, 1969)[8,9,10] to be important to task sensitivity to stress. Task layout, procedures and training regimen were developed to guarantee as far as possible that all Ss would actually perform the same task and that learning effects would not contribute significantly to performance variability in the experiment proper. To minimize the effects of individual differences in skill and of intra-individual variability in motivation, task parameters were adjusted on an individual basis to require each S to work at near-maximum capacity to maintain an arbitrary

baseline level of performance. To obtain performance measures with those qualities, Kelley's (1967)[11] "adaptive tracking" task and modifications of Adams' (1958) and Rashbass' (1955)[12,13] mental arithmetic tasks were selected for the study reported here. Two forms of mental arithmetic were employed in the hope of providing some basis for relating findings from British studies of hyperbaric environments to those of American studies of work-rest cycles and aircraft environments.

One of the firmest tenets of diving lore is that susceptibility to narcosis is greatly affected by "experience". Unfortunately, the "experience" referenced by this rule-of-thumb is necessarily multidimensional with respect to: totality of an individual's diving history; composition of breathing media and compression-decompression profile; number, duration, context, and interval between exposures; and nature of the presumed causal mechanisms. It appears that totality of an individual's diving history was the critical factor to the pioneers in inert gas narcosis, e.g. Shilling and Willgrube (1937)[14]. More recently some authorities have identified interval between exposures as a critical factor in susceptibility to narcosis of professional SCUBA divers. Lanphier (1964)[15] has reported observations from working dives which imply that susceptibility may increase when the interval is longer than 1 day; Bulenkov et al (1968)[16] recommend that divers should make at least one chamber run to 7 ATA per month. Concern with the interval between exposures leads naturally to questions about carry over of immunity between dissimilar dives. The experiment reported here provides some evidence regarding the relative effects of all three factors (individual's diving history, interval between dives, and similarity of dive profiles) on susceptibility to narcosis. Obviously the magnitudes of the effects found are important to interpretation of hyperbaric research, past and future, as well as to diving operations.

METHOD

Subjects

Eight hyperbaric chamber qualified enlisted men volunteered to participate in this study. All but one S had prior experience in hyperbaric studies.

Apparatus and Task Structure

Training and tests were conducted in the NAVSUBMEDRSCHLAB hyperbaric chamber which was built to withstand 150 psig. The main section of the chamber is 15 feet long and 9 feet in diameter. The S, seated in a student type desk-chair inside the chamber, viewed stimuli for each task through a 13 inch (internal) diameter port. His response was transmitted from a transducer mounted on the desk top to control and recording devices located outside the chamber. Viewing distance to the center of the displays was approximately 40 in. along the normal line of regard.

Mental arithmetic. Stimuli for the mental arithmetic tasks consisted of random samples from the populations of problems defined by Adams (1958)[12] and Rashbass (1955).[13] Rashbass requires multiplication of a two digit

number by a one digit number; Adams requires subtraction of a three digit number from the sum of a pair of such numbers. All Ss were required to solve both types of problems column by column from right to left as would normally be done in working with pencil and paper.

Each problem appeared on a 17 in. square rear projection screen as it would in a conventional printed arithmetic test. Angular height of the digits at S's eye exceeded 1 degree. S responded via an adding machine type keyboard to each problem as it was displayed on the screen. The responses were reflected to S by a row of four Industrial Electronics Engineers Bina-View displays mounted immediately below the projection screen. Rate of problem presentation was controlled by Hunter Model 111C timers.

Adaptive tracking. The task was pursuit tracking, via a pressure-sensitive controller, of a complex two-dimensional periodic function. The distinctive feature of Kelley's adaptive tracking task (1967)[11] is that target course is made to vary as a function of S's performance. In this experiment amplitude of target displacement on the oscilloscope varied directly with "C", the adaptive tracking factor. To maintain the visual identity of target and cursor on the oscilloscope face, S had to track with a small separation between them. Conventional tracking control-display relationships were implemented.

Figure 1 is a functional diagram of the tracking system. The major components of the system were: Measurement Systems controller Model 465 and tracking network Model 350 (cursor control); Electronic Associates TR-20 analog computer (function generator and signal conditioner); Tektronix four-trace oscilloscope Model RM-561A (display); and Hewlett-Packard data acquisition system Model 2012-C (A/D converter and recorder). The controller and tracking network were set for simple proportional control in each axis of the tracker's input to the

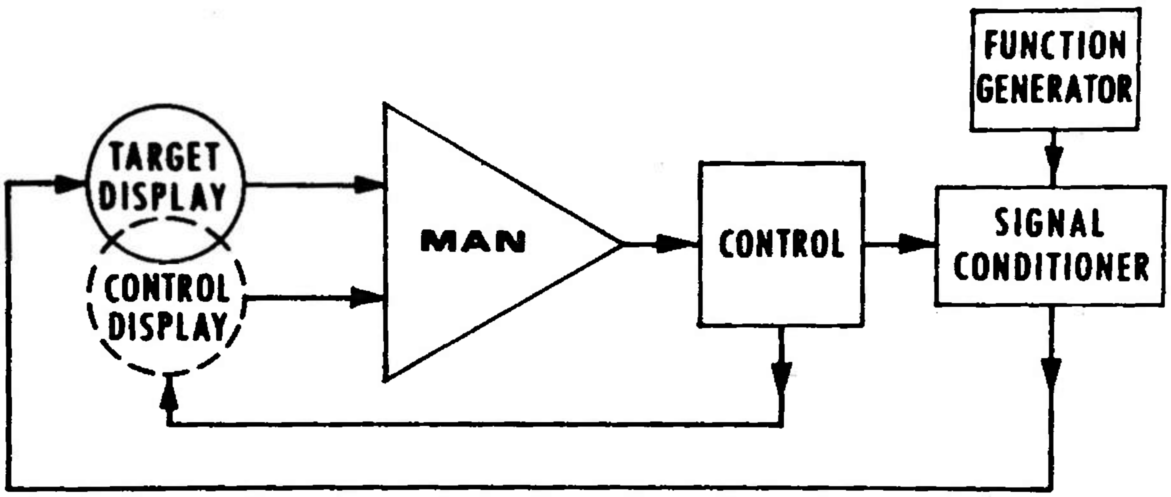

Fig. 1. Functional diagram of the adaptive tracking system.

oscilloscope display. The functions supplied to the adaptive tracking system for modification and display were $X=\sin(0.314)t + \sin(1.974)t$ and $Y=\cos(0.314)t + \cos(1.974)t$. The adaptive tracking factor which multiplied both X and Y was computed as, $C = \int(Ex + Ey + k)dt + C$. Ex and Ey are squared momentary errors in the two axes and k is the (arbitrary) error criterion. Change in "C" over the duration of a trial provided the measure of tracking proficiency.

Design and Procedure

The experiment was conducted in two replications of four Ss. Each man served as a S once a week for four weeks. The replication was divided into two cycles, S participated once at the control depth of 33 fsw (2 ATA) and once at the experimental depth of 198 fsw (7 ATA) in each. With that restriction on the sequences, only four orders of hyperbaric exposure are possible. One of the orders was assigned at random to each subject in a replication.*

During the five training sessions prior to the first hyperbaric exposure S was indoctrinated in the procedures to be followed in each task and practiced to near asymptotic levels of performance. In a session, two 30-problem sets of addition problems, one 30-problem set of multiplications, and four 3-min. tracking trials were administered. Initially arithmetic problems were presented for 14 seconds. As S's percentage of correct response varied over problem sets, rate of presentation was changed in an attempt to produce a base level of approximately 75 percent for each man. For the hyperbaric exposures, addition problems were presented for 5.5-10 sec. and multiplication problems were presented for 3.5-5 sec.

The compression and decompression phases of the 2 and 7 ATA exposures were made as similar as possible in terms of noise levels, temperature changes, and time at decompression stops by appropriate simulations during the shallow exposures. As attempts at misleading the Ss regarding the exposure pressure, these efforts were unsuccessful; in other respects they did introduce noise and confinement stresses as intended. In the 7 ATA exposures, compression rate was 80 ft/min and the decompression schedule was a modification of that specified in the U.S. Navy standard air decompression tables for exceptional exposures for 210 fsw for 50 minutes. The modifications consisted of substitution of oxygen for air as the breathing medium for 15 min at 30 fsw, 30 min at 20 fsw and at 10 fsw, and addition of a second 30 min oxygen period at 10 fsw to the normal duration of that stop. Oxygen was always administered by mask.

In addition to the arithmetic (MA) and tracking (TRK) tasks, a practical reaction time task (RT), the visually evoked response (VER), and the vector electrocardiogram (EKG) were administered during all exposures. The test program for administration of those tasks and measures is shown in Table 1. The mental arithmetic and tracking

The S scheduled for the 7272 order in the second replication was tested on the 2727 order.

Table 1. Test Program for All Hyperbaric Exposures

Stop	Elapsed Time	Measure	Mix
Bottom	3	RT, VER	Air
	17	MA	"
	32	TRK	"
		EKG	"
20 fsw	92	VER	0_2
	102	MA	"
	117	TRK	"
10 fsw	132	EKG	0_2
	144	RT, VER	"
	163	MA	Air
	178	TRK	0_2

tests were always administered in the sequence: addition, two 30-problem sets; multiplication, one 30-problem set; and tracking, two 3-min. trials.

RESULTS

Data analysis utilized the number of problems correctly completed on the mental arithmetic tasks and the mean change in the adaptive tracking factor "C" from beginning to end of each trial. Four-way analyses of variance (Stops(3) x Cycles(2) x Conditions(2) x Subjects(8)) were performed on the data for the three tasks.

The analysis of addition scores produced only one significant effect: stops (F [2,14] = 11.73, $p < .005$). This result reflects a fairly consistent performance decrement on the bottom under both 2 and 7 ATA conditions relative to performance at the 10 and 20 fsw stops. No interpretation supported by independent evidence can be offered. The multiplication task data analysis yielded no statistically reliable results. This finding may reflect differences between the multiplication tasks as administered in this study and in others. Ackles and Fowler (1971),[17] using the same type of multiplication problems, found a significant interactive effect of pressure and breathing medium in comparison of argon-oxygen and air at 1, 4, and 7 ATA. However, their analysis does not indicate whether there was a greater decrement with argon-oxygen than with air, or there was a decrement with argon-oxygen but not with air. The level of pretraining, mode of response (pencil-paper vs keyboard), format of response feedback, and dive profiles may have been factors contributing to the apparent insensitivity of both arithmetic tasks.

Analysis of the tracking data produced significant effects for: stops (F [2,14] = 8.26, $p < .005$); cycles (F [1,7] = 8.59, $p < .025$); stops x conditions (F [2,14] = 5.06, $p < .05$); and cycles x conditions (F [1,7] = 10.95, $p < .025$). Figure 2 represents the mean tracking scores at each stop for the 2 and 7 ATA exposures for the two cycles. The figure clearly indicates that the stops effect results from significantly lowered bottom scores on the 7 ATA exposures. The cycles effect derives from the overall improvement at all stops on the second cycle 7 ATA exposures. These same factors are also responsible for the two significant

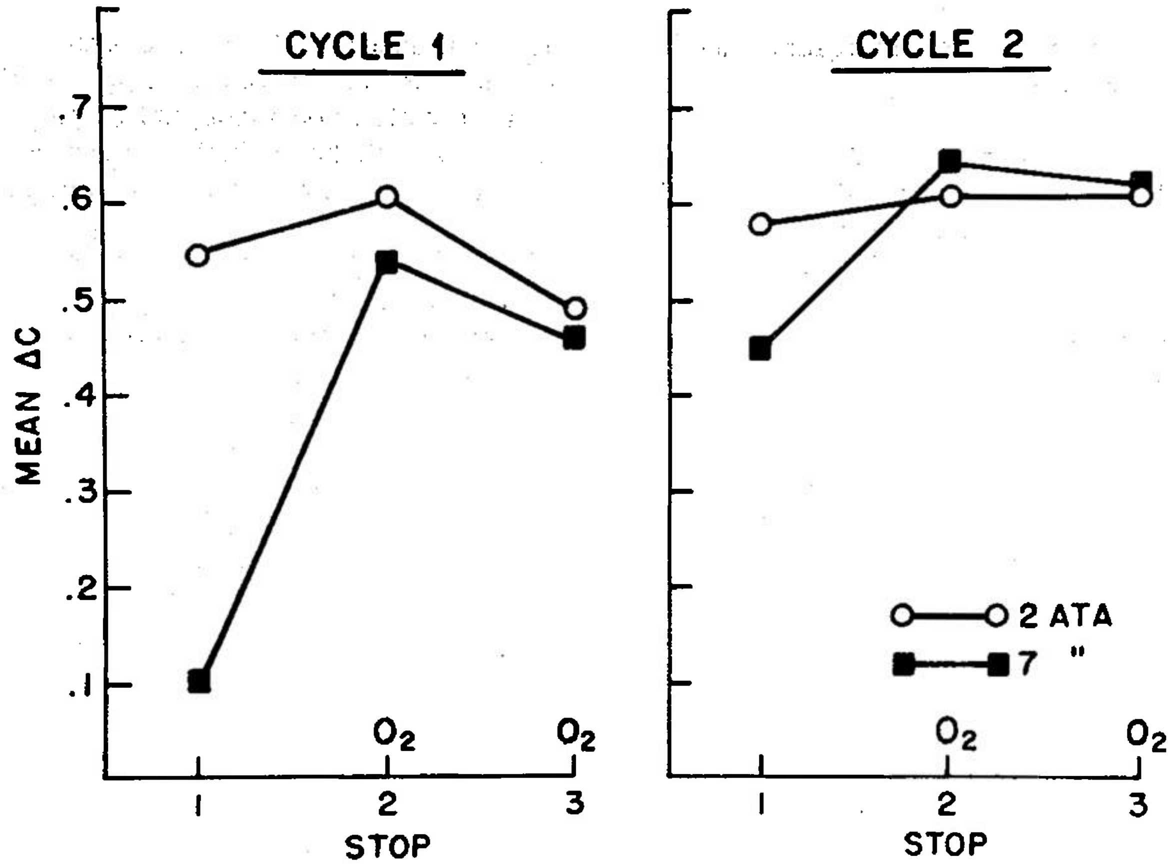

Fig. 2. Adaptive tracking score as a function of depth within exposure and of order and maximum depth of exposure.

interactions. The 2 ATA plots quite plainly demonstrate the lack of any change across stops or cycles, thus reiterating that significant findings resulted from the 7 ATA condition, and demonstrating the effectiveness of 2 ATA as a control depth for deeper dives.

DISCUSSION

Exposures to compressed air at 2 ATA and 7 ATA should provide useful test points for evaluation of performance measures. Descent to 33 fsw provides control, without induction of narcotic effects, for the obvious temporary discomforts of hyperbaric compression, e.g., perceptible pressure differential, increased temperature, and high noise levels. On descent to 198 fsw frank narcosis is often, but not invariably, produced. Demonstration of impaired performance on the adaptive tracking task for every S at the greater depth suggests that, in the form employed, it may provide the kind of sensitive and reliable test required for systematic study of hyperbaric and other stressors. As administered in this study neither mental arithmetic test possessed the characteristics

desired in a measure of inert gas narcosis.

Since the view is often expressed in the literature that cognition is more sensitive to narcosis than is motor performance (e.g., Biersner, 1972),[18] these findings might be surprising. There are a number of reasons why they shouldn't be. The empirical base for contrasting results from cognitive and motor tests in hyperbaric environments consists of a single study by Kiessling and Maag (1962)[19] and a series of studies by Baddeley and his coworkers (e.g., Baddeley, 1967; Baddeley, et al., 1968, and Davis et al., 1972)[20,21,22] aimed at resolution of conflicting findings within the series. Secondly, it appears that for the most ardent advocates of the cognitive-motor distinction with regard to narcosis (Kiessling and Maag, 1962)[19] the tasks used in the study reported here are not satisfactory representatives of either class. Thirdly, as Fleishman (1972)[23] has noted in summarizing his work since the 1950's, "Other psychologists have proposed categories of tasks in terms of broad human functions required to perform them... However, everything that is known about actual correlations between human performances indicates a considerable diversity of functions within each of these broad areas." A corollary noted by Fleishman, and confirmed by our exploratory studies of mental arithmetic, is that changes in task microstructure often change the function measured.

Of the many dimensions of experience named earlier only three varied, as a consequence of subject characteristics or the experimental design, such that their effect on susceptibility to narcosis could be evaluated: personal diving history, time between dives, and similarity of dive profiles. The range of hyperbaric experience in the group was about as large as it could be for a sample of eight men. In contrast, the relative effects of the two environments on tracking performances were very similar for these men. Whatever the more general effects of personal diving history may be on susceptibility to inert gas narcosis, none were evident in this experiment. Although the professional diving community seems to be convinced that interval between exposures affects man's susceptibility to inert gas narcosis (e.g., Miles, 1965, Flemming, 1971)[24,25] there have been no systematic studies of that relationship. In retrospect it is obvious that time between exposures should have been introduced formally into the design of this experiment rather than as a by-product of the control for order of exposure to 2 and 7 ATA. Apparently the range of intervals employed was too limited, given the sample size, to produce statistically reliable evidence for an effect on resistance to narcosis. The improvement in tracking performance at 7 ATA on the second test to a level close to that found in both tests at 2 ATA and the independence of that finding of order of exposure confirm that similarity of dive profiles is a dimension of experience important to susceptibility to inert gas narcosis. In the context of the study reported here "similarity" is defined by depth dependent attributes of the exposure. The 2 and 7 ATA situations were identical in all other respects.

The factors covariant with depth of exposure range in objectivity from variables as simple as pressure per se to those as complex as perceived risk. The mechanisms through which those variables might affect susceptibility to narcosis cover a corresponding gamut. Although the data do not permit positive identification of either the depth dependent attributes relevant to similiarity, or the mechanisms ultimately responsible for the effects observed, they do indicate that certain identifications are inappropriate and that some hypotheses are untenable. Clearly, the variables operative in open sea dives, but not in the chamber exposures reported here, are not necessary to reduction in narcotic susceptibility. This does not, of course, imply that participating in an open sea dive would not affect susceptibility in a subsequent chamber exposure. On the contrary, the sequence of exposures from more to less hostile environment should confer greater resistance to narcosis than the reverse. The findings also imply that long duration exposures are not required to affect susceptibility to narcosis; total time at depth in the exposures reported here was only a half hour. The foregoing are compatible with conventional hypotheses about the biological basis of inert gas narcosis; that it involves a change in the nervous system with short time constant that is local and reversible. Apparently no long term change in respiratory or circulatory function is necessary to produce increased resistance to narcosis.

In the conventional studies of human performance under hyperbaric conditions, there is either a single deep exposure, of long or short duration, or a series of shallow exposures specifically planned to provide repeated measures. The data reported here show that use of the second approach without regard for interval between exposures, or their order, should be avoided in research on inert gas narcosis. Unfortunately, it is not clear what portion of the existing literature suffers from that defect.

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13. ABSTRACT

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